Space Weather Working Team

The Space Weather Initiative

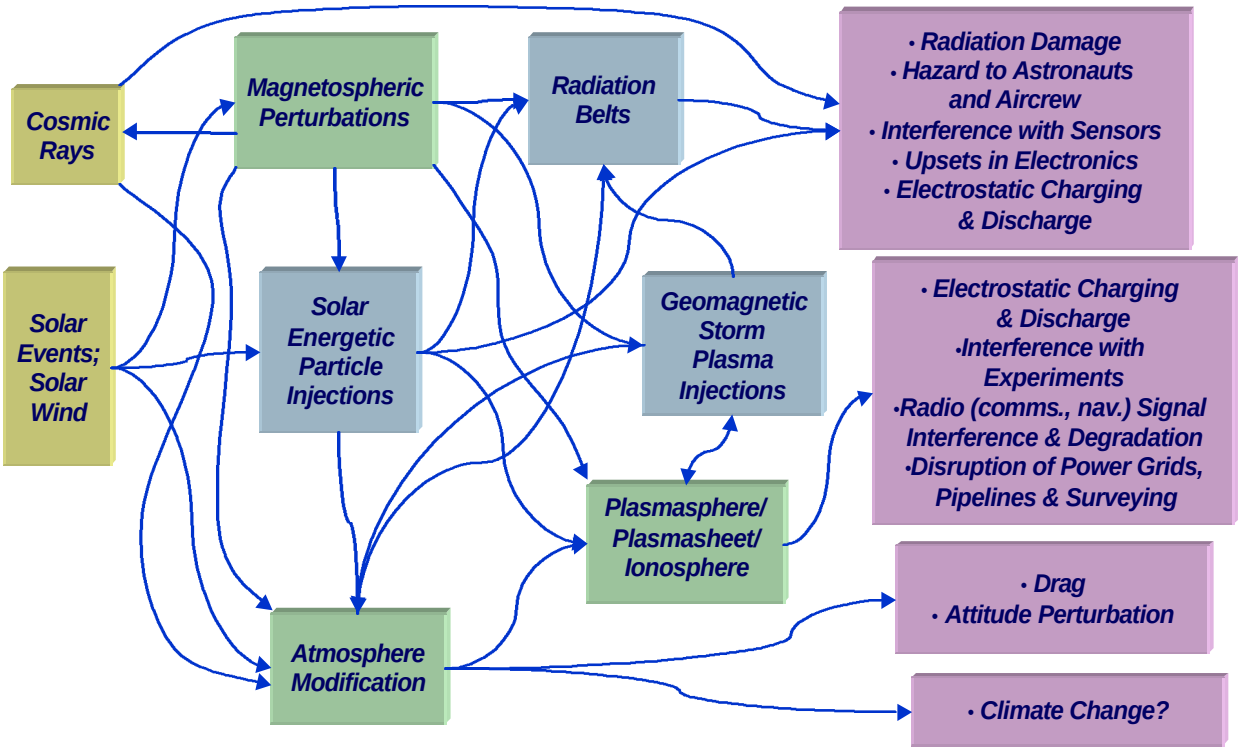
Briefing Summary

1. WHAT IS SPACE WEATHER?

Space Weather can be succinctly defined as: *conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can affect human life or health.*

It is clear from this that space weather is the collection of phenomena which gives rise to **effects** which concern society. Much of the science of space weather is a part of the larger field of solar-terrestrial physics. While the ESA Space Weather Initiative described in this paper addresses the establishment of user-oriented services and not directly scientific research, these efforts are and will remain underpinned to a large degree by solar terrestrial physics.

Space Weather may be more broadly interpreted to include other space environmental conditions such as particulate environments (meteoroids), the electromagnetic environment, and man's pollution of space (contamination, debris, radio pollution, etc.).

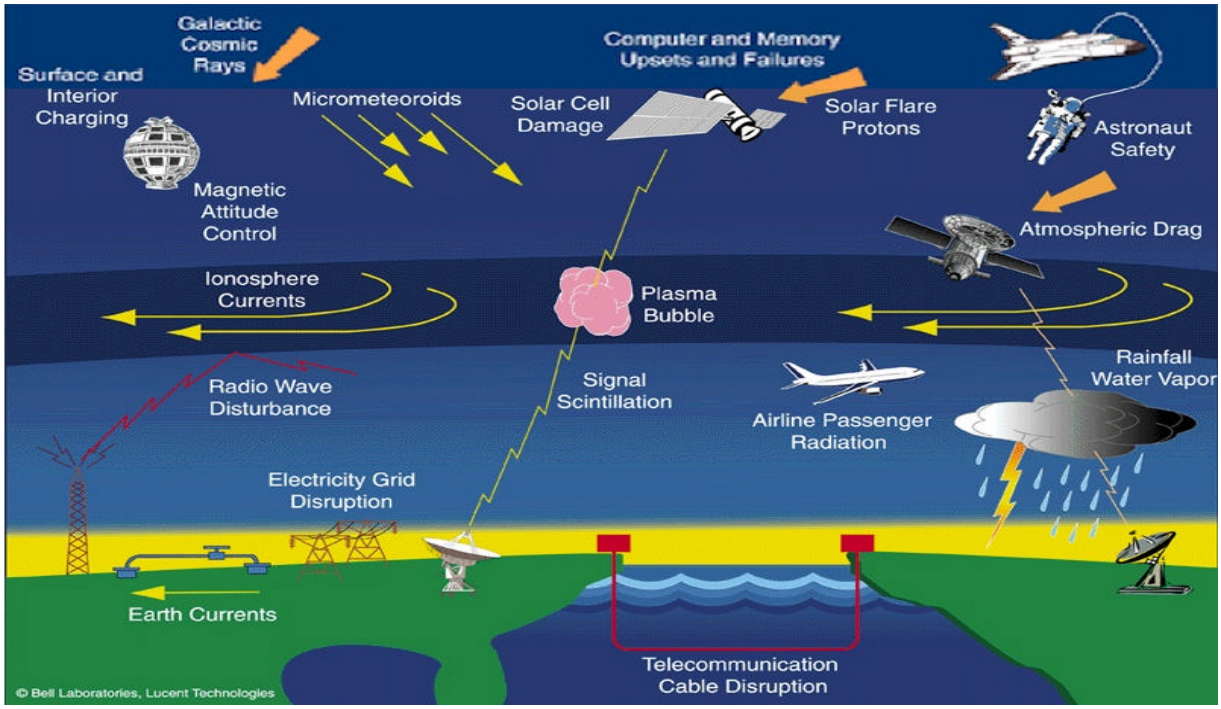


This figure illustrates the complex interactions which contribute to Space Weather, and the ultimate effects it can have. It is not intended to be comprehensive and much more information is available from the www sites associated with the ESA Initiative [1].

2. WHAT ARE THE EFFECTS OF SPACE WEATHER?

Space Weather affects a broad range of technologies and activities. The effects can be caused by different elements of the space weather system: radiation, plasmas, ionospheric currents, particulates, etc.. Over all sectors, the economic impact of is estimated to be some tens of millions of Euros per year and since the effects are increasing as technology advances, the economic impact will also grow. The effects, some of which are illustrated in the cartoon below, include:

- Terrestrial power distribution networks: These are affected by additional current flows in cables induced by currents in the ionosphere. The current surges can destroy equipment, necessitate operational system reconfiguration or special designs.
- Terrestrial communications: Some systems which make use of transmission via the ionosphere are seriously affected. Many of these systems are military.
- Users of space-based trans-ionospheric services: Radio propagation through the ionosphere can be seriously perturbed. Ground-space communications and navigation services can be disrupted, as well as radar-based remote sensing.
- Oil and mineral prospecting and operations: Geomagnetic field variations can perturb magnetic readings routinely used in these fields.
- Defence: The defence sector makes increasing use of communications and navigation services which are affected. Space systems are important to this sector. Over-the-horizon radars are also affected.
- Airlines and aircraft developers: Advanced avionics systems are becoming susceptible to cosmic radiation effects. Aircrew are exposed to doses of cosmic radiation which European legislation now requires be monitored
- Space agencies and commercial space system operators: Space systems are subject to numerous types of serious radiation damage and interference. Radiation hazards to astronauts are significant. Spacecraft can discharge following plasma-induced charging, causing anomalies. Rapid atmospheric variations can affect spacecraft orbits and stabilisation.
- Climate: Space weather is suspected to have important effects on climate. These have to be accounted for in global change programmes. The "Maunder Minimum" in solar activity of the 17th century led to a series of extremely cold winters which added significantly to the hardship of European nations.

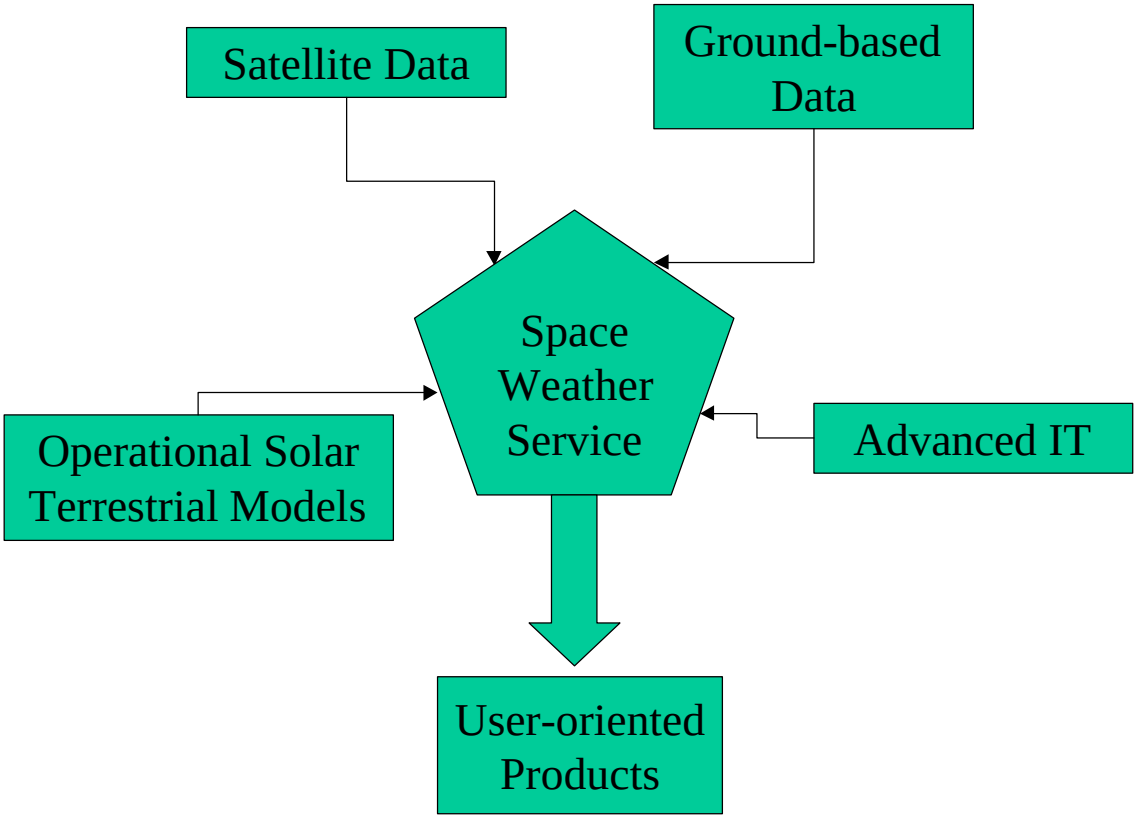


3. WHAT IS A SPACE WEATHER SERVICE?

A space weather service provides end-users in the various affected sectors with tailored products to avoid or reduce space weather hazards through design or operation. While in many sectors the goal of reliable forecasting can only be reached through much further research, the data and services which can be provided are already proving valuable in certain sectors such as communication, spacecraft and power grids.

A space weather service federates ground and space based measurement of the solar-terrestrial environment, not to perform science, but to derive products. To do so, it makes use of resources existing because of solar-terrestrial physics programmes but must deploy independent resources to augment these measurements and to guarantee the continuity and response required by a service. A service must respond to evolving user needs and develop products for supply of user-oriented parameters for direct use by engineers.

Elements of the service include advanced data processing and information technologies to exploit the data and execute simulations of the space weather systems.



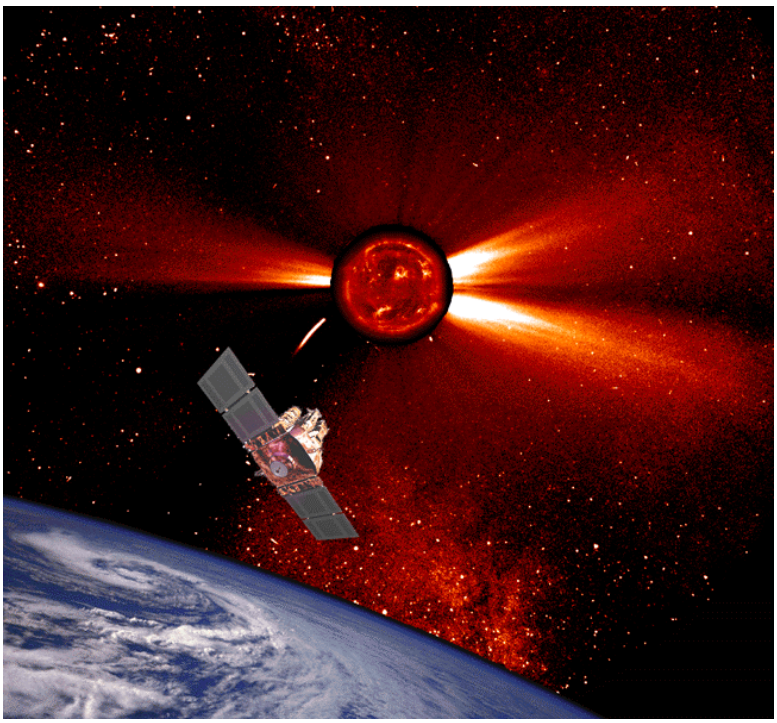
4. SCIENCE OR APPLICATIONS? – SCOPE OF THE INITIATIVE

It is important to emphasise that while space weather services are built on a foundation of results from solar terrestrial physics, the establishment of these services is not itself a scientific subject. Its relevance for Europe and the Agency lies in the increasing concern over space weather ***effects*** to a range of human activities.

Space weather services are nevertheless excellent examples of the ***spin-off*** from the scientific programme, the results of which make possible genuine social benefits. ESA, through the solar-terrestrial physics part of the science programme, has been at the forefront of the development of the understanding of the physics of the sun, the production of energetic solar events, their propagation through the interplanetary medium and the consequent responses of the magnetosphere, ionosphere and atmosphere to the events. The SOHO and Ulysses projects have been key tools in exploring this highly complex sun-earth connection and it is expected that the excellence they represent will continue with Cluster-II and eventually Solar Orbiter.

While data from science projects can in the short-term provide valuable resources for developing and operating space weather services, science projects have very different goals and constraints than operational space weather projects. SOHO provides excellent data on the sun and the heliosphere. This has become crucial for space weather service developers and operators and certainly shows the way forward by demonstrating measurement possibilities and the usefulness of the data in building products. However, it is not necessarily the role of the ESA science programme to continue this provision. A sustainable service, on the other hand, would have this as a priority. Furthermore, whereas it may be desirable for operational reasons to return data from a science mission some days after the observation and at very high resolution, the requirements of an operational system are for real-time data at a (probably lower) resolution determined by the service requirements. Of course, long-term continuous data sets acquired for an operational space weather service become available for use in scientific research too.

In the US the Space Weather service activities are run mainly by NOAA, along with the National Weather Service. While NASA's motivation in this area is related mainly to scientific exploration, they collaborate with NOAA in making its expertise and resources available and also have interests in space weather effects on spacecraft.



5. WHY IS IT IMPORTANT FOR EUROPE?

Space weather related problems are increasing because of technological advances. Advances in space and on the ground make many systems (satellites, ground-based communications, aircraft, power grids,..) susceptible to disruption from space weather disturbances (solar, radiation belt, geomagnetic, ionospheric, atmospheric, etc.). In addition, the expanding population of astronauts and growth in air travel further increase the importance of the effects of cosmic radiation on humans.

Analyses [2] have identified and studied in detail several important benefits of a European space weather programme and the service it will provide. These include:

- ***Economic benefits:***
  Improvement in the ability to circumvent space weather problems in all domains. A space weather service would deliver products to improve the quality and efficiency of design and operation of increasingly sensitive technologies.
- ***Strategic benefits:***
  Europe is heavily reliant on US capabilities in this field; there is no guarantee that the open data policies in the US will continue. Indeed there are examples of export restrictions impeding European access to models in this domain. In order to safeguard access, agreements are needed, based on contribution of European resources;
- ***Defence benefits:***
  Defence forces rely heavily on technological systems which can be strongly affected by space weather. A space weather programme would provide independent access or a firm basis for collaboration;
- ***Research and Development***
  A space Weather programme allows opportunities for cutting-edge technology developments in many space and ground technologies of strategic interest to European industry;
- ***Collaboration***
  Several European member states have world-class resources which can gain considerably from a collaborative framework. Facilitation of this collaboration is the natural role of ESA. In order to establish wider collaboration, space weather capabilities need to be established.
- ***Education and Outreach***
  The general public and education sector have considerable demonstrated interest in space weather. Space weather services demonstrate to the general public the relevance of space research in general and solar terrestrial physics in particular, but also stimulate interest in, and support for, European space activities. Strongly growing interest is apparent in the media and general public's following of solar events and visible effects at earth such as spectacular aurora.

European contributions to the development of the world-wide Space Weather knowledge are well-recognised. In the US and Japan significant programmes are starting including both scientific and user-service elements. In the US this is through the NASA *Living with a Star* programme which while mainly scientific in its thrust contains important application elements, and also through the activities of NOAA and the DoD. ESA plans to explore collaboration with some of these actors as well as within member states' agencies and other organisations, including the EU.

Space Aircrew Power Defense Surveying

6. IS A SPACE WEATHER SERVICE POSSIBLE?

Excellent progress has been made over the last decade in our understanding of the solar-terrestrial system. While it is true that some important features of that system lack detailed understanding (such as the phenomena on the solar surface which give rise to *Coronal Mass Ejections*, or *Solar Flares*), many elements shown in the diagram in section 1 have progressed significantly. Science missions will continue to improve our understanding in these areas, provided that the scientific interest remains. Otherwise it would be the responsibility of a space weather research and development activity to further such understanding.

While a long-term challenge is to establish a capability to predict hazardous conditions at Earth based on solar precursors or other *space weather drivers*, a space weather service is much more than this.

A service provides a framework for continuous observations of space weather, warning of hazardous conditions based on tested and proven methods and maintaining a historical record of the space weather. This latter point is crucial and often overlooked; these data are needed for investigation *after the event* of the environment associated with suspected space weather induced problems. They are also needed to build the capability to improve the services.

Some examples are provided below of services which already exist and the developments anticipated over the next decade.

Needs (examples)	Observation	Future development
Warning of geomagnetic storms for ground-based activities	**Plasma structures in the solar wind known often to cause geomagnetic storms**	**Effectiveness of solar wind structures in storm initiation**
Warning of radiation hazard to astronauts	**Position and magnitude of solar flares**	**Influence of coronal mass ejections and shocks**
Prediction of drag on satellites	**Solar and geomagnetic variations**	**Use of better data and model developments**
Warning of hazards to satellites	**Solar flares and coronal mass ejections; Shocks in the solar wind**	**Better models of the radiation belts and hot plasma injections**
Prediction and warnings of radio signal perturbations	**Ionospheric and solar measurements**	**More complete data; perturbation models of the ionosphere/plasma-sphere**
Archive of Space Weather Data	**Many space based and ground-based data sources**	**Augment system: more data points, better types of measurement, easier access**
…		

The current capabilities are provided by co-operation between ground-based solar and geophysical observatories and space-based measurements. This co-ordination is often led by NOAA and includes Japan and some European states. European space-based data are not formally exploited in this co-ordinated effort and indeed arrangements for co-operation are often ad-hoc.

7. WHAT ESA AND ITS PARTNERS PROPOSE TO DO

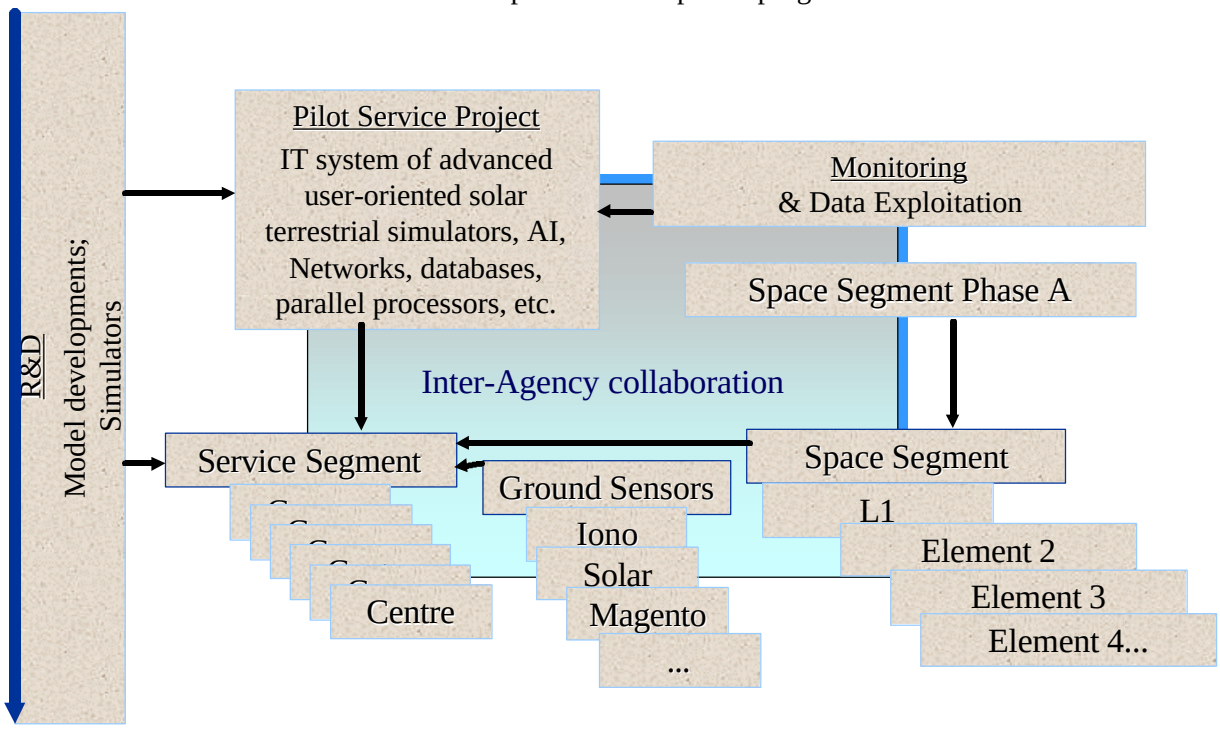
Important progress has been made in defining the requirements and possible ways forward to establish a European space weather programme by major studies undertaken under ESA contracts [2]. In the next phase ESA proposes, together with its European partners, and in collaboration with others world-wide, to:

- prototype a "service-segment" which should ingest data from existing widely disparate sources, perform large-scale simulations, make predictions of space weather hazards. The prototype performance would be evaluated;
- continue and expand the policy of flying small space weather monitors on as many European spacecraft as possible;
- study possible system and space segment options, considering the implications of potential world-wide collaboration;
- perform research and development in key areas of the space weather field, to establish products of value to users and ensure scientific advances are exploited to this end;
- study the nature of an ultimate service at the European level.
- establish partnerships and collaborations;

For achieving these objectives, ESA will place research and development contracts with European entities. It will rely on the advice of an *Inter-Agency Space Weather Co-ordination Group* and a *Space Weather Working Team*. It will organise regular community meetings through a *European Space Weather Forum*. Through these means it will be ensured that the ESA activities are in response to the established needs of service exploiters.

Such activities will make it possible to co-ordinate the development and exploitation of various member states' space and ground-based activities which will be brought into a world-wide co-ordination.

Following the pilot project phase, it is expected that the collaborators in the Initiative will work towards the establishment of an optional development programme.



References

1. ESA maintains its space weather site at
http://www.estec.esa.nl/wmwww/spweather/ ;
The consortia working with ESA in the Initiative have sites accessible via:
http://www.estec.esa.nl/wmwww/spweather/spweathstudies.htm

2. Studies of a future European Space Weather Programme undertaken by a consortium led by Alcatel Space and a consortium led by CLRC Rutherford Laboratories (see
http://www.estec.esa.nl/wmwww/spweather/spweathstudies.htm)